Bureau of Economic Geology (BEG)

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- Research unit of The University of Texas at Austin
- ~120 researchers, ~60 staff, ~50 postdocs + GRAs

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- Repository for millions of cores and geophysical logs
- Basic and applied research, all around the world
- Conducts research focusing on the intersection of energy, the environment, and the economy
- 2 Divisions: “Energy” and “Environment”
- http://www.beg.utexas.edu/

Jackson School of Geosciences

Bureau of Economic Geology

- Established in 1995 after gift by John A. “Jack” Jackson
  - Department of Geological Sciences
  - Bureau of Economic Geology
  - UT Institute for Geophysics
- Largest geosciences department in US
  - ~350 undergraduates
  - ~250 graduate students

Two speakers

Bureau of Economic Geology

Jean-Philippe "JP" Nicot
Senior Research Scientist
Bureau of Economic Geology

Bridget R. Scanlon
Senior Research Scientist
Bureau of Economic Geology

Texas Shale Plays and Impacts on Aquifers: w/ a focus on the Eagle Ford

J.-P. Nicot and Bridget Scanlon

Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

Workshop on the Status
of the Geological and Hydrogeological Knowledge
in the Sabinas and Burgos Basins, Mexico

UNAM, Mexico City, Mexico – June 1-3, 2016

Outline 1/3

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- A few generalities
  - MX-TX stratigraphic equivalence
  - Legal/operational background
  - Historical perspective
  - Water use overview
- Eagle Ford Shale water use and impact on aquifers
- Aquifer contamination issues

Terminology: shale or not shale?

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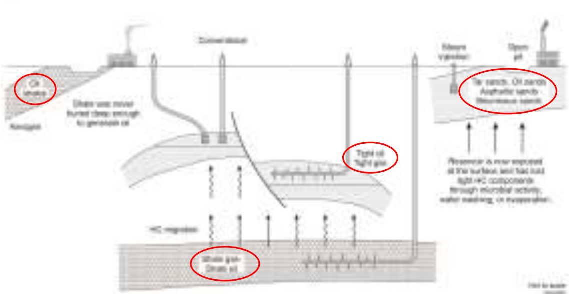
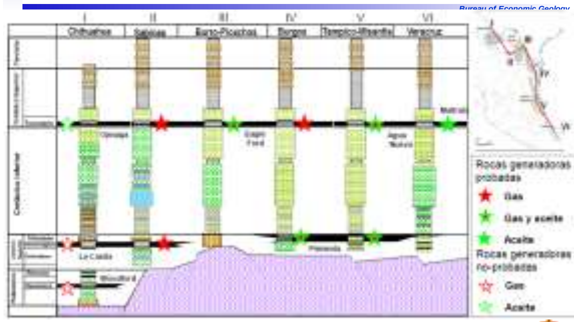


Burgos Basin (ARI, 2013)

Source: EIA, 2013

Bureau of Economic Geology

Source: Pemex, 2012

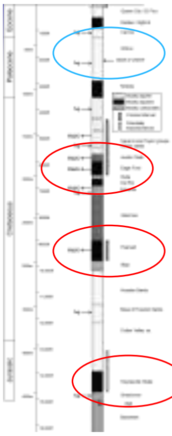


Source: Alcocer (Pemex), 2012

Bureau of Economic Geology

Source: ARI, 2013 from GSA, 1991

Source: GSA, 1991



EF oil window at the Dimmit-Zavala county line

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- Eagle Ford Shale at depths of 1500-3000 m (5000-10,000 ft)
- Deeper Pearsall Shale tested in the late 2000's
- Haynesville Shale untested
- Major Aquifers are part of the Carrizo-Wilcox aquifer system
- Some water sourced from the Queen City Sparta and Gulf Coast aquifers

U.S Specificities: Legal background in Texas

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- Surface water belongs to the state but is mostly appropriated through the prior appropriation doctrine "*first in time, first in right*".
- Groundwater belongs to the landowner; rule of capture toned-down by GCD's
- <u>Split Estate</u>: surface vs. mineral rights
- Mineral rights are private, not owned by the government
- Mineral rights win over surface rights; right to use surface including use of groundwater and non-state surface water (in same lease) to develop the property

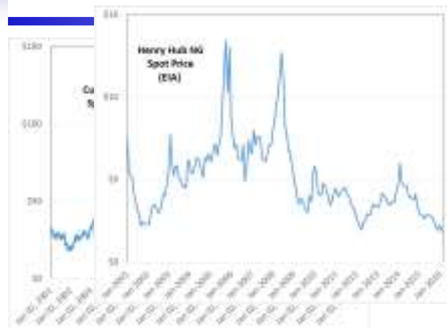
Operational landscape

Bureau of Economic Geology

- Major, large independents, independents, mom and pop's
- HF was perfected by independents
- 100's of operators in each play (for most)
- Vast number of supporting service companies all competing for business (trucking, treatment, pipelines, etc)
- Dense <u>network of suppliers</u> combined with <u>private ownership</u>, <u>entrepreneurial independents</u>, and <u>existing regulatory</u> framework explain the quick expansion of HF in Texas

Historical perspective

Bureau of Economic Geology



at the

:

n gas)

"Shale" drilling rigs as of November 2015

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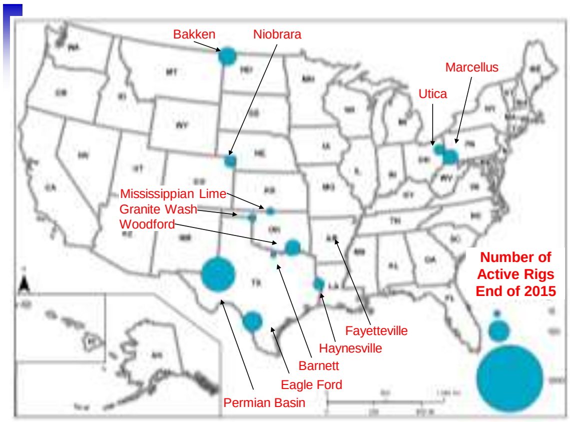
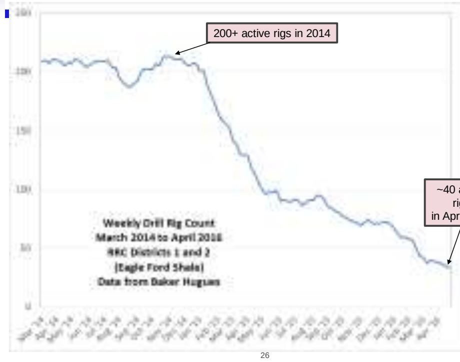
- Woodford, OK 38
- Barnett, TX 6
- Niobrara, CO 27
- **Eagle Ford, TX 75**
- Fayetteville, AR 4
- Granite Wash, TX+OK 13
- Marcellus, PA+WV 43
- Utica, OH 21
- Haynesville, TX+LA 25
- **Permian Basin, TX(+NM) 229**
- **Bakken, ND(+WY) 63**
- Mississippian, OK(+KS) 12

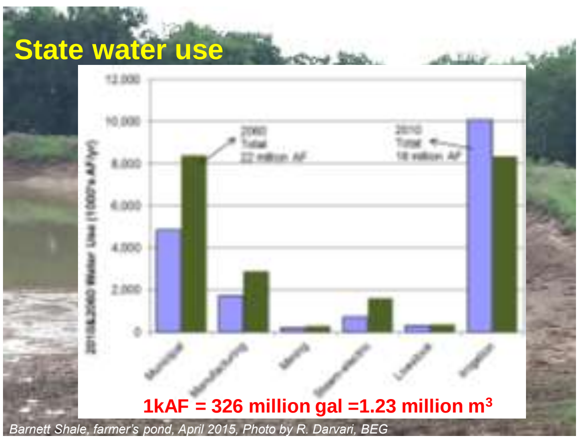


Rig count decline in the Barnett Shale (gas)

Rig count decline in the Eagle Ford Shale (oil)



State water use

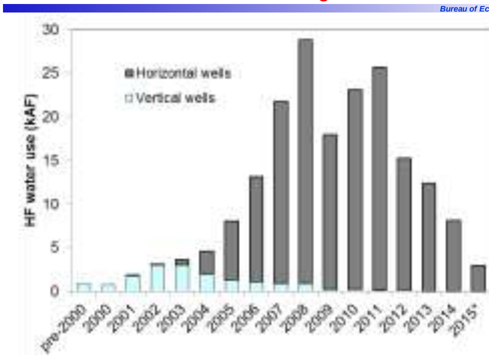


1kAF = 326 million gal =1.23 million m^3

Barnett Shale, farmer's pond, April 2015, Photo by R. Darvari, BEG

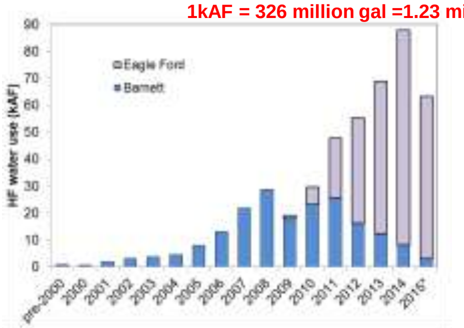
Barnett Shale – Hor. Vs. Vert.

1kAF = 326 million gal =1.23 million m^3



Eagle Ford Shale: half of the water use for HF in Texas

1kAF = 326 million gal =1.23 million m^3



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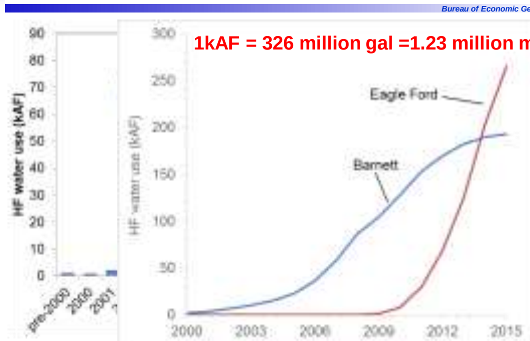


Water source

Bureau of Economic Geology

- Often times hard to characterize accurately
- Surface water / Groundwater
- Municipal or industrial waste water; recycle / reuse
- Use vs. consumption

Outline 2/3

Bureau of Economic Geology

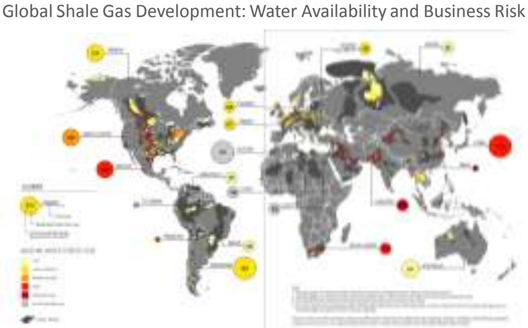
- A few generalities
- Eagle Ford Shale water use and impact on aquifers
  - Water scarcity vs. water demand
  - General context of EF water use
  - Brackish water alternative
  - Natural gas and water demand
- Aquifer contamination issues

Water Use for Hydraulic Fracturing in the Eagle Ford Shale Play

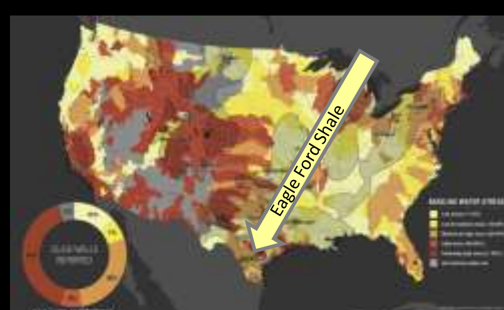
Bridget R. Scanlon, J.-P. Nicot, Robert C. Reedy, Svetlana Ikonnikova, and Michael Young

Bureau of Economic Geology
Jackson School of Geosciences
University of Texas at Austin

Global Shale Gas Development: Water Availability and Business Risk



World Resources Institute, 2014



Freyman et al., CERES, 2013

Unconventional Resource Plays

Sloan Foundation: Marcellus, Fayetteville, Barnett, Eagle Ford, and Bakken plays
Mitchell Foundation: Permian Basin

- Natural Gas
- Oil
- Tight sands
- Basins

Source: National Geographic

Water Use for Hydraulic Fracturing (million gallons/well)

- Natural Gas
- Oil
- Tight sands
- Basins

Freyman et al., 2013; Nicot et al., 2014; Scanlon et al., 2014; Kondash & Vengosh, 2015

Questions

Water scarcity = demand > supply

1. What is the **water demand** for hydraulic fracturing (HF)?
2. How does **water intensity of oil production** from conventional reservoirs compare with that from unconventional reservoirs?
3. What are the **impacts** of HF on water resources?
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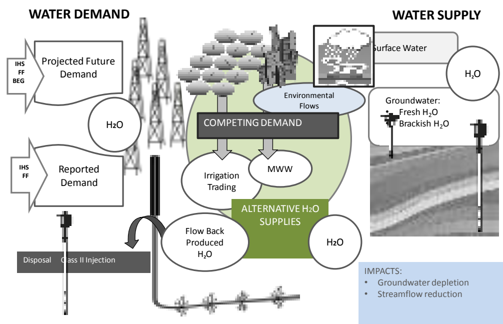
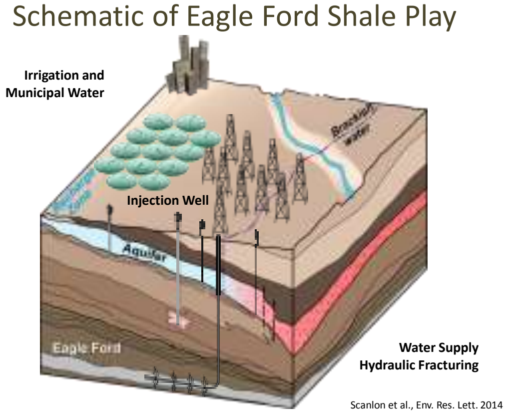
Methodology for Assessing Water Energy Nexus



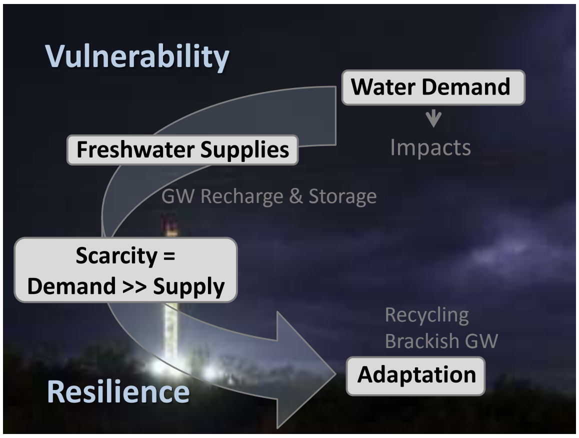
Schematic of Eagle Ford Shale Play



Scanlon et al., Env. Res. Lett. 2014

Eagle Ford Shale Play

Scanlon et al., Env. Res. Lett. 2014



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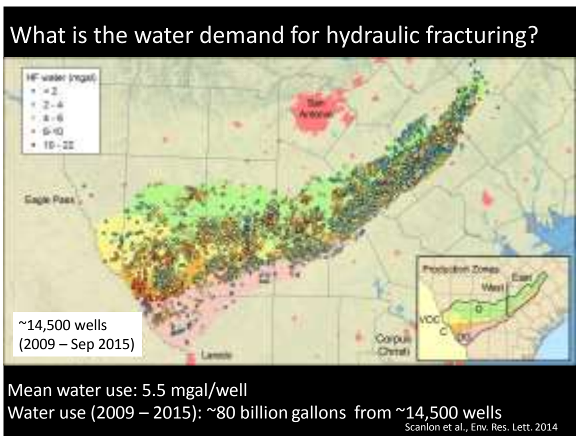

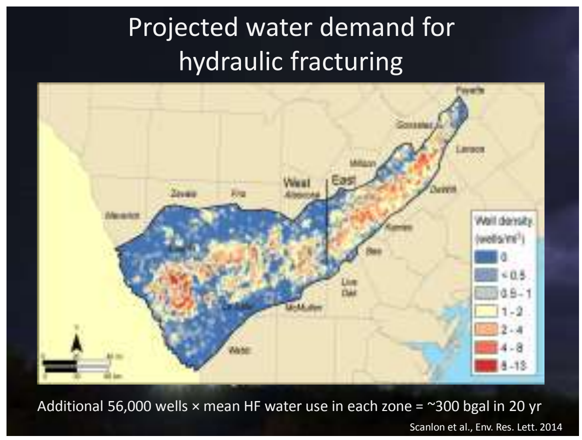

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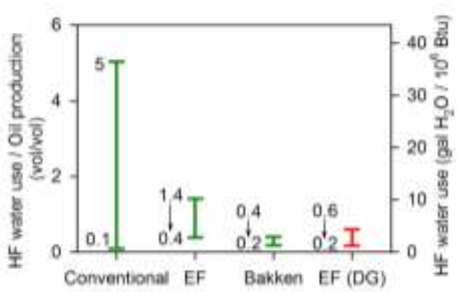
Water Use per Unit of Energy

Zone	HF	Energy	HF/Energy	EUR	HF/EUR
	mgal/well	mgal/well	H_2O/OE	mgal/well	H_2O/OE
Oil	4.6	3.0	1.52	13	0.34

Scanlon et al., ES&T. 2014

How does water use for shale oil production compare with conventional oil production?



Scanlon et al., ES&T. 2014

ENVIRONMENTAL Science & Technology

Response to Comment on "Comparison of Water Use for Hydraulic Fracturing for Unconventional Oil and Gas versus Conventional Oil"

- Bakken: low water injectivity limited water flooding
- CO_2 injection higher water to oil ratio than water flooding (Wu and Chiu, 2011 (conventional WAG), Modeling in Bakken, increased production 15 – 18% after 18 yr continuous CO_2 injection
- Refracturing: generally < 20% of wells

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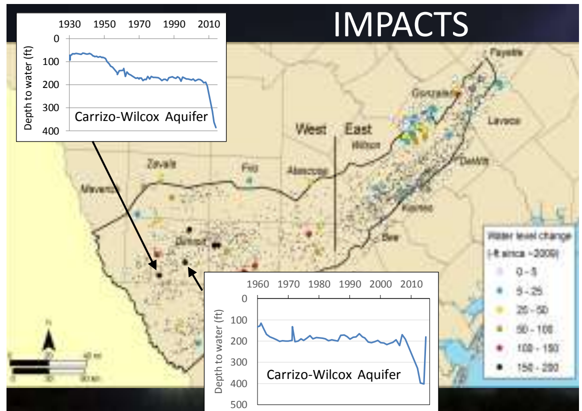
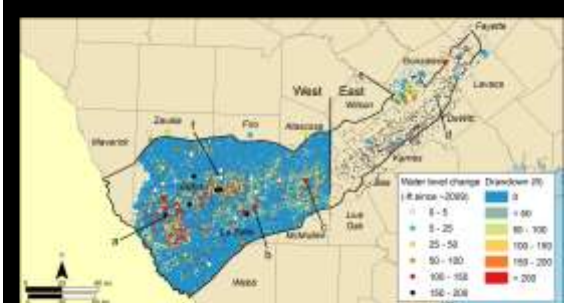


Scanlon et al., Env. Res. Lett. 2014

IMPACTS



Estimated drawdown in the aquifer in the west:
150 – 200 ft over 6% of the area

Long-term Impacts of Irrigation Pumping on Groundwater Levels

Projected water use for shale gas extraction = 10% of GW depletion for past irrigation

Scanlon et al., Env. Res. Lett. 2014

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Water Supplies: GW Recharge

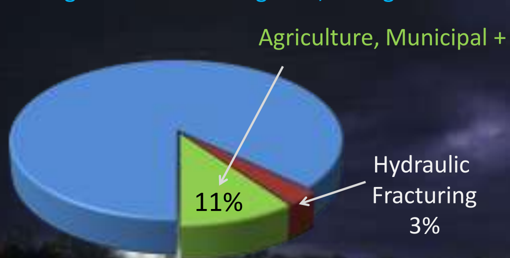
Recharge: 20 – 60 bgal/yr
400 – 1,200 bgal over 20 yr life of the play

Scanlon et al., Env. Res. Lett. 2014

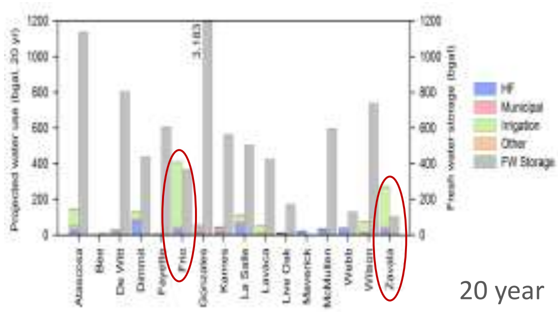
Aquifers in Eagle Ford Area

Water Supplies: GW Storage

At the Play Level:
Fresh groundwater storage: 10,000 bgal



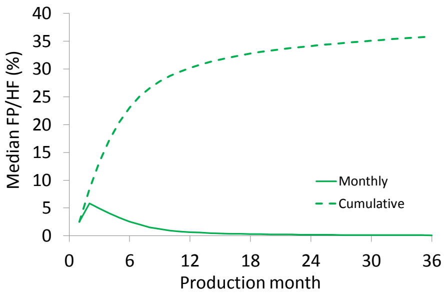
At the County Level: Demand vs GW Storage



20 year
Demand Projections

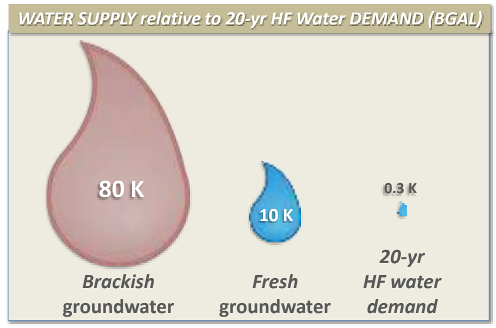
Scanlon et al., Env. Res. Lett. 2014

Alternatives to Freshwater: Flow back/Produced water



Scanlon et al., Env. Res. Lett. 2014

Alternatives to Freshwater: Brackish Groundwater



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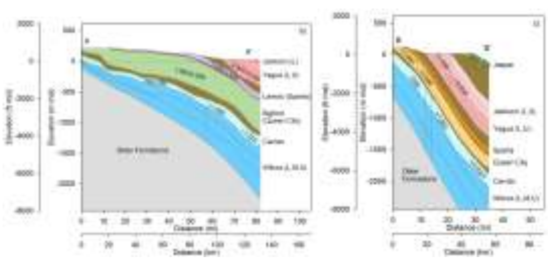
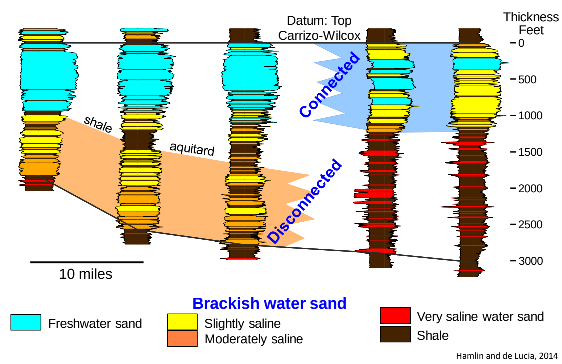
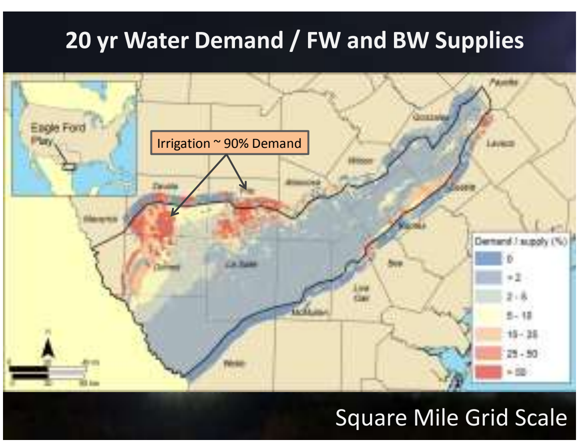
Scanlon et al., Env. Res. Lett. 2014

Cross Sections



Carrizo-Wilcox Stratigraphic Cross Section Showing Connected and Disconnected Brackish Groundwater





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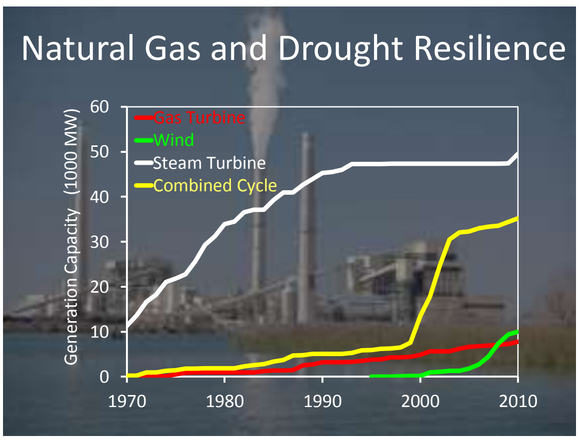
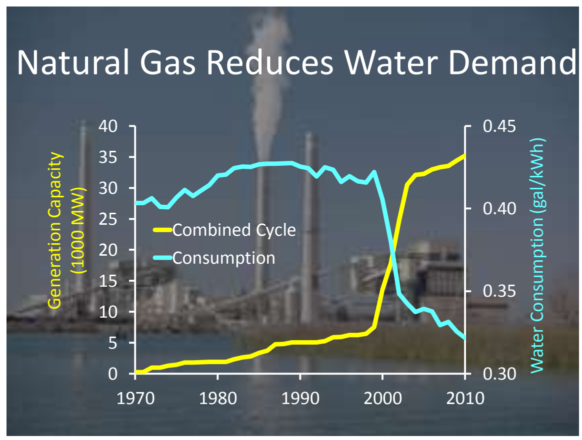
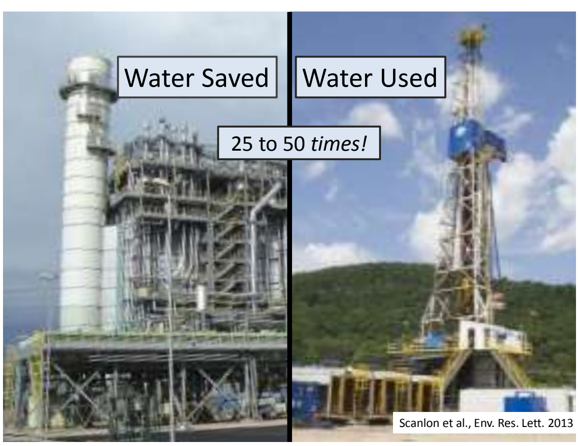
Net Impact of Hydraulic Fracturing on Water Resources

Net impact of gas production: **saves water**

- Water use for shale gas extraction = **6%** of water consumed to generate electricity using that gas
- Water consumed in natural gas power generation is ~ **1/3rd** of that used in coal or nuclear plants
- Water saved not collocated with water used for HF

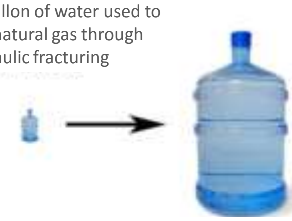






Water Savings

For every gallon of water used to produce natural gas through hydraulic fracturing



Texas saved 33 gallons of water by generating electricity with that natural gas instead of coal or nuclear fuel (in 2011)

Questions and Answers

1. What is the water demand for hydraulic fracturing (HF)?
   Eagle Ford, consumed ~ 80 bgal from 14,500 wells (2009 – 2015)
   Projected water demand, ~300 bgal from 56,000 wells in 20 years
2. What are the impacts of HF on water resources?
   Groundwater level declines ≤ 200 ft.
2. Is hydraulic fracturing vulnerable to water scarcity? (20 years)
   FW supplies: GW storage: 10,000 bgal; HF = 3% of fresh GW storage
   Alternative Sources: Brackish GW: 80,000 bgal; HF = 0.4% of BW
5. What is the net impact of water use for HF on water resources?
   Use of shale gas in power generation saves water relative to coal or nuclear plants

Outline 3/3

Bureau of Economic Geology

- A few generalities
- Eagle Ford Shale water use and impact on aquifers
- Aquifer contamination issues
  - Baseline sampling
  - Dissolved gas sampling methods
  - U.S. studies
  - Texas studies

Baseline vs. monitoring

Bureau of Economic Geology

- Baseline ("pre-drill"):
  - Adhoc sampling of available wells (domestic wells)
  - non-optimized locations with screen(s) spanning several formations
  - Goal is to follow regulations, insure legal cover in case of litigation, gain a general understanding of the local water quality, and improve relations with residents.
- Monitoring:
  - Deliberate sampling of carefully located dedicated wells at specific narrow depth intervals
  - Multiyear sampling
  - For local ("performance") or regional ("sentry") purposes

Baseline sampling

Bureau of Economic Geology

State	Sampling radius (ft)	Number of Wells	Timing* (*presumed liability)	Post-Drill Sampling
PA*	2500	All	1 year after*	No
WV*	1000	Owner request	Prior to drilling	TBD
CO	2640	All (to 4 max)	1 year prior	Yes, 3 (1, 3, 6 yrs)
OH	1500	All	Prior to drilling	No
MD	2640	All	1 year prior	No
NY	1000	All	Prior to site disturbance	Yes, TBD
CA	1500	All	Prior to drilling	Yes
IL (draft)	1500	All (3 samples)	Prior to drilling	Yes, 3 (6, 18, 30 mos)
WY	2640	All (to 4 max)	Prior to drilling	Yes, 2 (1, 4 yrs)
MI (draft)	1320	Up to 10	< 6 mos. prior	No

None: TX, OK, NM

Bob Puls, OK Water Survey, 2014

Potential contaminants

- Dissolved gases, light alkanes, BTEX
- Brine
- HF fluid additives
- Flowback / produced water

Gasland and other faucets on fire


Colorado


Pennsylvania


Barnett Shale, Texas


Natural seeps
New-York State

Bubbling wells Barnett Shale area


Methane outgassing

Methane characteristics

- Average methane concentration in atmosphere is 1.8 ppmv (CO_2 is ~400 ppmv)
- Methane is nontoxic but can displace air and is explosive (Lower Explosive Limit LEL is 5% air volume - UEL is 15%)
- CH_4 solubility of 25-30 mg/L at atmospheric pressure depending on temperature
- Dissolved concentration >10 mg/L can generate high methane levels in confined spaces (wellhead)
- Action level 10 mg/L (7 mg/L in PA)

Dissolved gas sampling methods

- Time average concentrations: passive diffusion devices (wellbore)
- Point-in-time samples: surface
  - Direct fill method
  - Bucket method
  - Isotech method
  - Flow-through vial method
  - Copper tubing method
- Point-in-time samples: wellbore
  - Downhole sampler – O&G industry


Kuster

Passive diffusion samplers

- Several commercially available models
- Installed in a monitoring well for weeks
- Designed for VOCs, not clear of they work well for CH_4 and C2+ HCs, especially isotopic composition

Direct fill method

- Fill up a bottle or a vial and quickly cap it

Bucket method

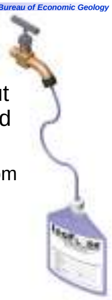
Courtesy: Gorody ppt

Used by USGS, EPA and several other groups

Isotech "Isoflask"

- Developed by the private company Isotech/Weatherford and has become a fool-proof standard but needs to be processed by Isotech

http://www.isotechlabs.com



Flow-through vial method

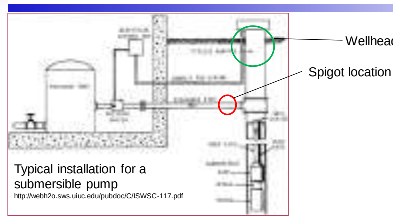
- Variation on the Isotech method
- Used by BEG

Copper tube method

- The highest standard
- Can use a back-pressure regulator to sample at pressure
- But cumbersome
- Important to know the sampling method to correctly interpret the field results

Courtesy of Dr. D. Pinti

No exposure to air or vaccum



Typical installation for a submersible pump
http://webh2o.sws.uiuc.edu/pubdoc/C/ISWSC-117.pdf

- Add acid, biocide
- Storage of upside-down vial in a cooler with ice
- Analyze within a week

Source of methane

- Th
  -
  -
- Bi
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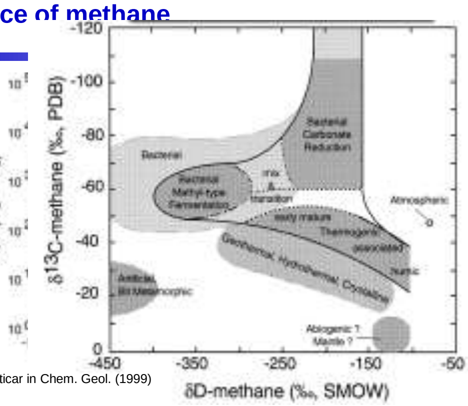


Whiticar in Chem. Geol. (1999)

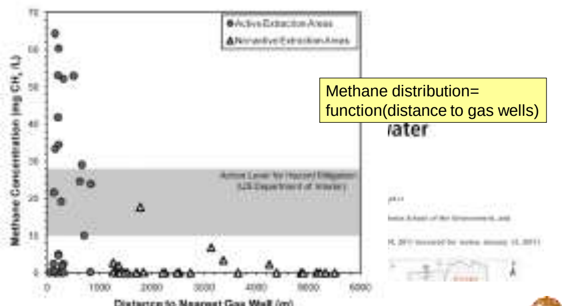
A few dissolved methane studies in the U.S.

Bureau of Economic Geology

- 10,000's of "pre-drill" baseline samples taken by industry – not always made public
- Most well-known and publicized: Marcellus studies by Duke University team, industry-funded team and U.S.G.S: still controversial
- More and more are being published

Marcellus, PA

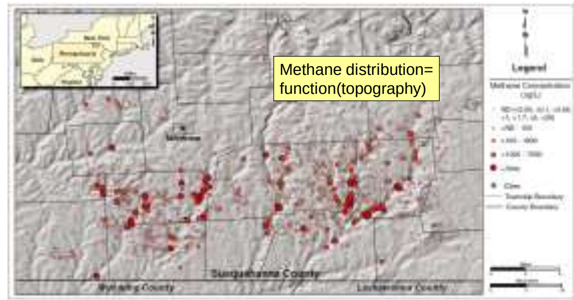
Bureau of Economic Geology



Osborn et al., 2011, PNAS

Several studies – Marcellus

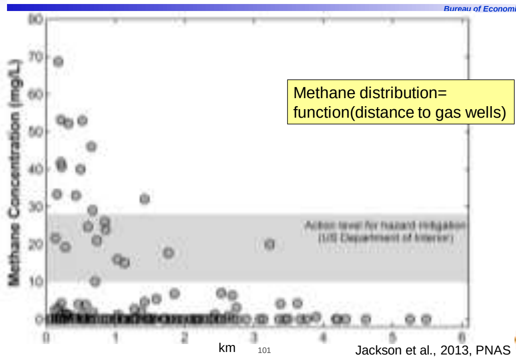
Bureau of Economic Geology



Molofsky et al., 2013, Groundwater

Several studies - Marcellus

Bureau of Economic Geology



Jackson et al., 2013, PNAS

Several studies – Marcellus

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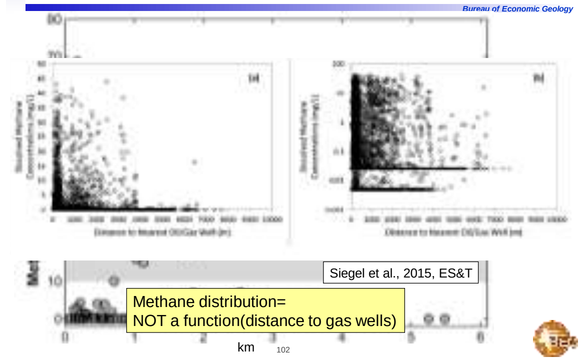
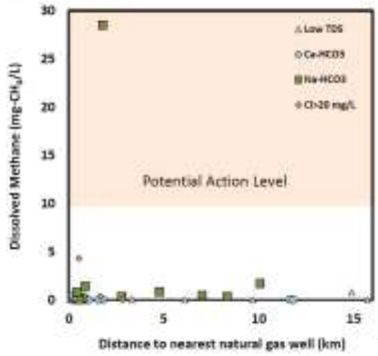


Marcellus, NY

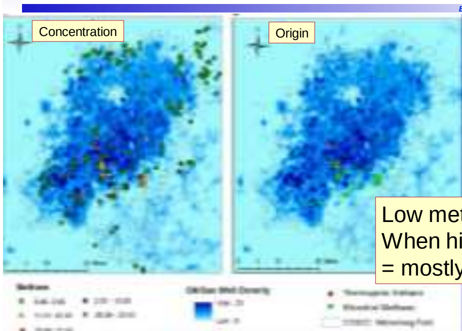
Fayetteville, AR



- No methane

Warner et al., 2013, CGA

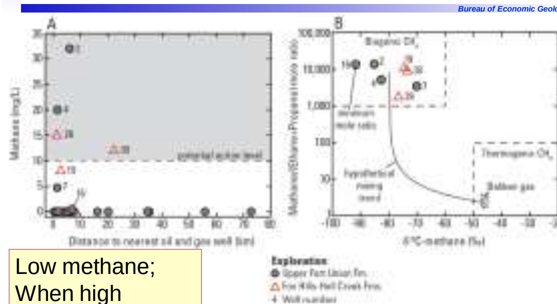
Several studies – Niobrara / Wattenberg



Low methane;
When high
= mostly microbial

Li and Carlston, 2014, ES&T

Several studies – Bakken



Low methane;
When high
= mostly microbial

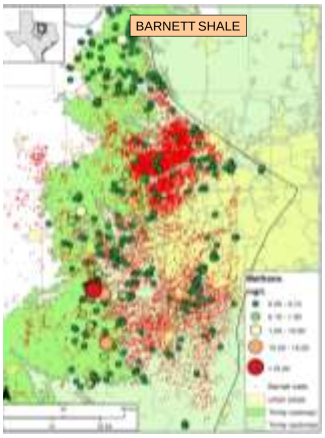
McMahon et al., 2014, Groundwater

A few dissolved methane studies in the U.S.

- 10,000's of "pre-drill" baseline samples taken by industry – not always made public
- Most well-known and publicized: Marcellus studies by Duke University team, industry-funded team and U.S.G.S: still controversial
- No or little methane found: Colorado Wattenberg field, Fayetteville, Bakken
- Barnett Sh.: mostly no methane except the "Range Resources" case area
- Haynesville Sh.: lots of microbial methane, some thermogenic
- Eagle Ford Sh.: complex, doesn't seem thermogenic

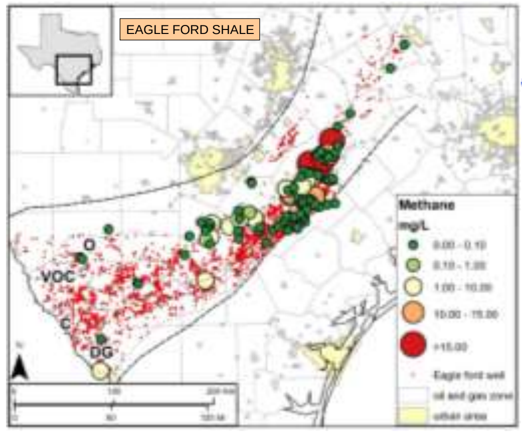
Large campaign

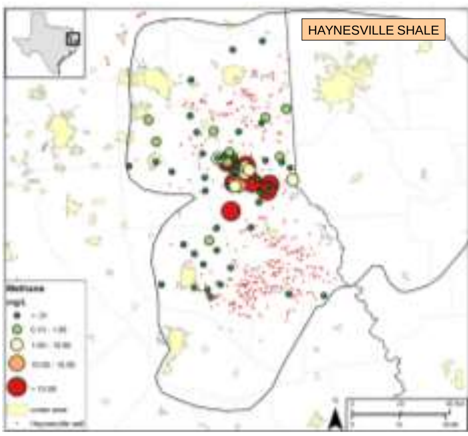
- Domestic, irrigation, municipal wells
- Consistent sampling method
- 843 water samples from different plays
  - 555 / 612 Barnett shale footprint (with du- and tri-plicates)
  - 118 Eagle Ford shale footprint
  - 70 Haynesville-TX shale footprint
  - 43 Delaware Basin (West Texas)
- In-house analyses of dissolved gases and carbon isotopes + major and minor species
- Dissolved noble gases and produced gas in selected areas of the Barnett

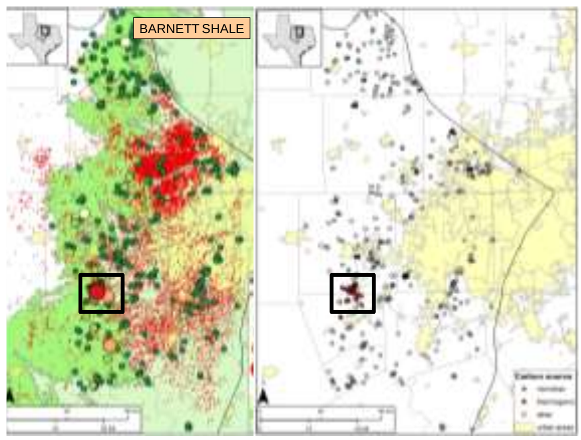


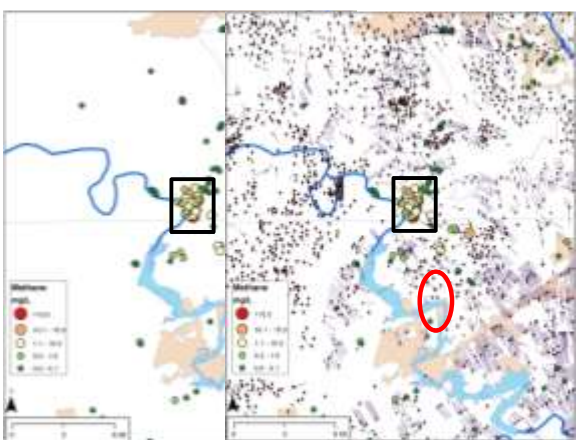
Dissolved Methane in the Barnett Footprint

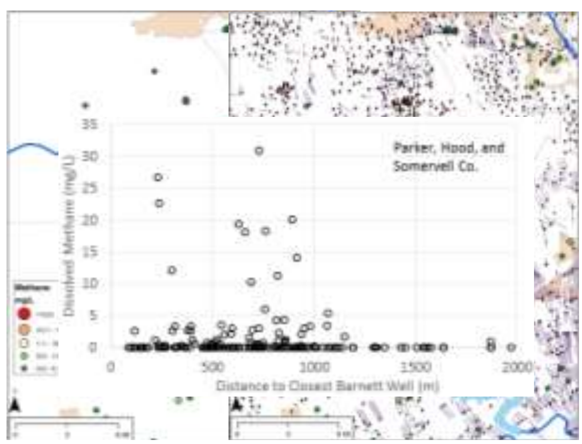
- 500+ water samples of fresh-water aquifers
- Most are <0.1 mg/L (action level is 10 mg/L)
- Several low microbial concentrations
- Local high thermogenic concentrations
- Similar findings in other Texas plays

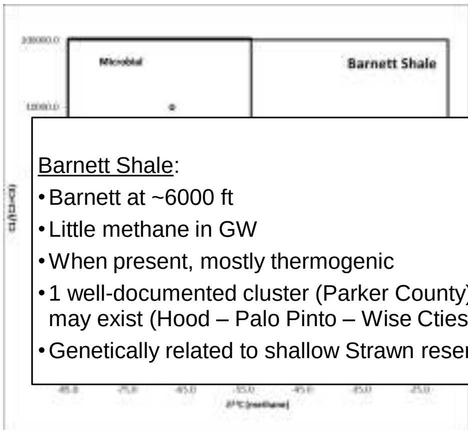






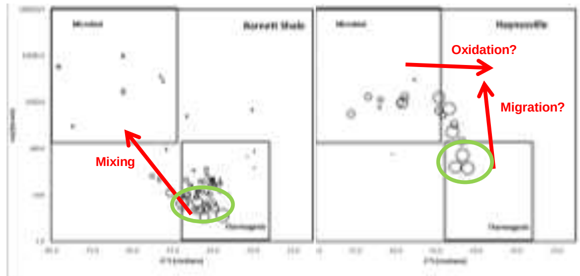


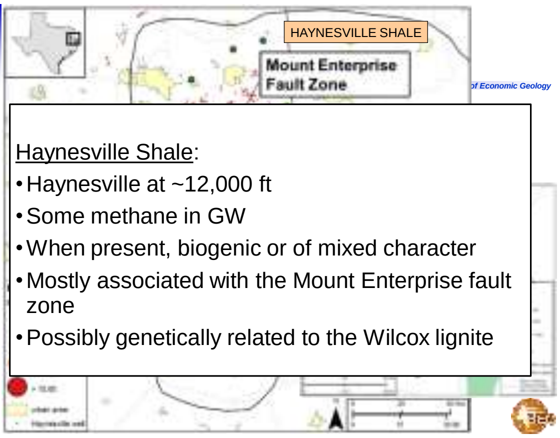




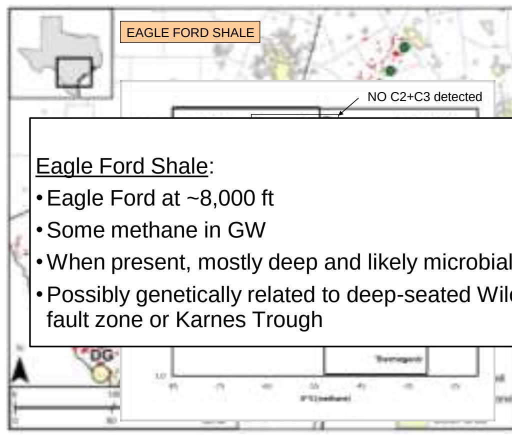
Barnett Shale:
- Barnett at ~6000 ft
- Little methane in GW
- When present, mostly thermogenic
- 1 well-documented cluster (Parker County), others may exist (Hood – Palo Pinto – Wise Cties)
- Genetically related to shallow Strawn reservoirs

Barnett vs. Haynesville





Haynesville Shale:
- Haynesville at ~12,000 ft
- Some methane in GW
- When present, biogenic or of mixed character
- Mostly associated with the Mount Enterprise fault zone
- Possibly genetically related to the Wilcox lignite



Eagle Ford Shale:
- Eagle Ford at ~8,000 ft
- Some methane in GW
- When present, mostly deep and likely microbial
- Possibly genetically related to deep-seated Wilcox fault zone or Karnes Trough

Recommended analyses

- Several entities have released or publicized guidelines: states (OH, WY, CO), associations (NGWA, AWWA), academic institutions (LLNL), O&G companies (Chesapeake)
- Variable level of requirements
- Should be adjusted to local geology and conditions and other potential local sources of contamination

Recommended analyses

- Tier 1 field parameters:
  - Eh, DO, pH, temperature, conductivity, alkalinity, [TSS, turbidity, H_2S]
- Tier 1 lab parameters:
  - Major anions (e.g., SO_4^{2-}, Cl^-) and cations (e.g., Na^+, Ca^{2+}, Mg^{2+}, K^+) [IC]
  - Minor elements often also diagnostic (e.g., Br^-, F^-, NH_4^+, PO_4, NO_3, Fe, Mn, Ba, B, Li, Sr) [ICP suite]
  - Regulated trace metals and metalloids (e.g., As, Pb, Cr, Se)
  - Dissolved methane and light alkanes
  - Organic compounds (e.g., regulated BTEX, TPH or TOC)

Recommended analyses

- Tier 2 if anomaly is suspected or
  - If high methane (0.1, 1, 10 mg/L?): do C isotope work
  - If BTEX or TPH: do some compound-specific analysis (surfactants, alcohols, etc)
  - If Ba and no sulfate: do radionuclides (e.g., Ra-226, Ra-228, U)
  - Dissolved O_2, N_2, Ar

Recommended analyses

Bureau of Economic Geology

- Tier 3: scientific investigations
  - Water isotopes
  - C, O isotopes and D of alkanes and CO_2
  - Noble gases
  - S of sulfate and H_2S
  - Sr isotopes
  - All families of additives (polyacrylamides, alcohols, biocides, glycols, surfactants)